FEDERAL FIRE COUNCIL

Washington, D.C. 20405

February 9, 1968

To All Mailing Lists,
Federal Fire Council

SUBJECT: Review of a Collection of Ten Papers on the Problem of Fire Risks in Oxygen-Enriched Environments

The members of the Committee on Research and Technology have determined that they might assist in the acquisition and dissemination of technical fire research reports by condensing them and helping to interpret them for members of the Federal Fire Council. Accordingly, you will find enclosed a condensed and modified technical report, the original writer of which is denoted after the title.

In this condensation, some interpretations have been made by the person making the digest and observations are made of the more significant points of the research. Specific areas of application and use are suggested which we hope will be of importance to you.

Readers interested in the original paper are referred to the library system references on the cover page. The committee would be happy to hear of your comments concerning this venture, which we hope may be worth continuing.

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Chairman
Committee on Research
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Enclosure

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RESEARCH REPORT DIGEST NO. 1

COMMITTEE ON RESEARCH AND TECHNOLOGY

A Collection of Ten Papers on the Problem of Fire Risks in Oxygen-Enriched Environments

by Various Authors

These papers condensed and interpreted by R. L. Tuve, Member, Committee on Research and Technology

KEY WORDS: Fire, Explosion, Flammability, Burning Rate, Hydrocarbons, Flight Vehicle, Special Atmospheres, Oxygen Enriched Environment, Hyperbaric Chambers

RELEVANCE OF THESE PAPERS: In view of the recent "Apollo" catastrophe it would be particularly apropos for members of the fire protection profession to be well informed concerning the general effects of combustion under high oxygen conditions. The papers and reports in this collection are not meant to be a complete literature review of the subject but will give the reader some insight as to how the problem has been attacked from many points of view concerning oxygen-diluting gases, high and low pressures, types of combustibles, methods of test and some effects on man or animals.

Brief comments are given concerning the content of each paper followed by each author's summary and conclusions.

DIGEST:

1. Denison, D., Ernsting, J., and Cresswell, A. W., "The Fire Risks to Man of Oxygen Rich Gas Environments", Royal Air Force Institute of Aviation Medicine, Report 320, Apr. 1965.

This is an excellent report of experimental fire studies utilizing a life-size brass manikin and dead pigs, each subject clothed with denim flying suit materials. The clothing was ignited in a chamber containing nitrogen and oxygen at varying concentrations from 100% oxygen to 21% oxygen at 1 atmosphere pressure and then 100% O_2 at 1/3 atm. and 50% O_2 at 1/2 atm. Completely subject-enveloping water spray systems and borax type fireproofing were used in an effort to assess control of damage to the subject.

Summary

This paper describes a series of 45 experiments upon the effects of igniting clothing (mounted on a brass dummy, or on dead pigs), in oxygen-rich environments.

Fires were studied in gas environments with oxygen partial pressures ranging from 0.2 to 1.0 atmospheres. The effects of variations in the type, fit and flame proofing of clothing and in the detailed use of the water spray extinguishing system were noted.

These experiments strongly suggest that:

(i) The risks of igniting a man are great., increased in these environments.

(ii) Fires in oxygen-rich environments are of a fundamentally different character to those in air.

(iii) Igniting a clothed man in these environments may lead to fatal damage within 5 to 20 seconds of onset.

(iv) A dense local water spray can control this fire but a manually operated system could not hope to arrest it in the few seconds available.

(v) The damage to the man is critically dependent upon the type, fit and fireproofing of his clothing and on the timing density and distribution of the extinguishing water sprays.

2. Turner, H. L. and Segal, L., "Fire Behavior and Protection in Hyperbaric Chambers", Fire Technology, Vol. 1, No. 4, November 1965.

This experimental report is slanted toward the practical fire and fire protection problems of environments containing ordinary medical therapy combustibles when air pressures were raised to 4 atmospheres.

Conclusions

It is felt that the materials tested, although a limited number, are representative of the types of combustibles likely to be found in a hyperbaric chamber. On this basis, it appears justifiable to state that all flammable or combustible materials will burn more rapidly in a chamber under pressure than they would normally.

Table 4. Effect of Pressure on Rate of Burning

Pressure		Percent increase over burning at one atmosphere					
Atmospheres	PSIG	Ethyl Alcohol	Methyl Ethyl Ketone	Diethyl Ether	Cotton Sateen		Methenamine
					NFPA test	Empirical test	
2	15	29	33	No test	31	34	36
3	30	58	58	35	45	41	53
4	45	81	120	58	No test	79	68

The increase in burning rate is not a linear function of the increase in pressure for any of the materials tested. For all materials, there is a rather remarkably uniform increase of approximately one-third when the pressure is raised from one to two atmospheres. The effect of higher pressures on the burning rate is much less uniform.

The greater oxygen content of the chamber atmosphere at higher-than-normal pressure accelerates the rate of combustion for all materials. Conversely, the greater nitrogen content acts to quench combustion, but to a lesser degree and to varying degrees for different materials.

The flame resistance of textiles, either chemically applied or inherent in the fibers, is not significantly reduced at pressures up to four atmospheres.

3. Moran, H. E. Jr., and Bertrchy, A. W., "Flammability Limits for Mixtures of Hydrocarbon Fuels, Air, and Halogen Compounds," Naval Research Laboratory Report No. 4121, Feb. 25, 1953.

This report deals with gas mixtures of flammable fuel vapors and extinguishing materials of the vaporizing liquid types. Bureau of Mines type flammability limit curves were determined and one part of the work was devoted to determining the effect of oxygen enrichment.

Summary

Some interest has been shown in the effect on flammability limits of increase in the oxygen content of air above the normal 21 percent by volume. Consequently, flammability curves were determined for mixtures of n-pentane vapor, perfluoromethane, (CF_4) and "air" in which the oxygen was increased to 31.3 percent and to 38.7 percent.

The procedure was identical to that described before except that oxygen was substituted for part of the air so that the final mixture was equivalent to that which would be obtained using air containing the higher concentrations of oxygen.

It can be seen that the increase in oxygen in the "air" produces relatively little change in the slope of the lower limit arm of the flammability curve, but produces a large displacement of the upper limit arm of the curve, resulting in a large increase in the minimal amount of diluent inerting gas required to completely inhibit combustion.

4. Van Dolah, R. W., Zabetakis, M. G., Burgess, D. S., Scott, G. S., "Review of Fire and Explosion Hazards of Flight Vehicle Combustibles," (BuMines, Dept. Int.) ASD Technical Report 61-178, Aeronautical Systems Division, AFSC, USAF, Wright-Patterson A.F. Base.

This report covers many considerations pertinent to its subject. A most important finding is given concerning the dependence of minimum ignition energy (in millijoules) on ambient pressure and oxygen content in O_2-N_2 mixture. Minimum ignition energy for propane decreases rapidly as oxygen concentration increases and less energy is required at one atmosphere pressure than at 1/2 atm.

5. Johnson, J. E., Woods, F. J. "Flammability in Unusual Atmospheres," Naval Research Laboratory Report No. 6470, October 31, 1966.

This report discusses many factors of the fire problem of hyperbaric atmospheres and gives the results of a series of newly devised exposure chamber flammability tests of fabrics under N_2, He, O_2 - enriched air and increased pressure environment exposure.

Summary

The effect of oxygen enrichment, increased pressure, and substitution of helium for oxygen on the flammability of fabrics and other solid materials was studied. Oxygen enrichment had the most pronounced effect. Linear burning rates were increased by a factor of about 2 or 3 when oxygen content was increased from 21% to 31%. Oxygen enrichment was especially effective in inducing ignition. Many materials which did not ignite at 21% oxygen, ignited and burned readily when oxygen content was increased to 31% or 41%.

Increase in pressure of a given atmosphere often had a pronounced effect on the ignition of materials, especially in borderline cases. In atmospheres of a given composition, ignition frequently occurred at higher pressures where no ignition occurred at lower pressures.

Substitution of helium for nitrogen as the diluent gas was found to decrease the tendency of a material to ignite. This effect was shown to be caused largely by the relatively high thermal conductivity of helium, which dissipated the heat from the igniter. Once ignited, however, most of the materials tested had a decidedly greater burning rate in the helium mixtures than in nitrogen mixtures.

Although a number of the potentially combustible materials studied did not ignite in ordinary air at one atmosphere pressure, upon increase of oxygen content to 41% almost all these materials ignited and burned.

6. Chianta, M. A., and Stoll, A. M., "Effect of Oxygen Enriched Atmosphere on Burning Rate of Fabrics," Naval Air Development Center Report MA-6316, Aug. 30, 1963.

This is a short but significant report on the flammability aspects of a polyamide textile fabric (HT-1) and cotton twill in oxygen-enriched atmospheres at 4.6 psia.

Summary

To determine the optimal atmospheric conditions attainable in space capsules, the burning pattern of several fabrics in oxygen-enriched environments (20-100% O_2) at 4.6 psia pressure has been studied. The data demonstrate that at the pressure used, burning is enhanced by oxygen enrichment regardless of the ratio of oxygen to nitrogen. A definite though small advantage exhibited by the synthetic material HT-1 over the other two fabrics implies that it would be profitable to pursue the study by varying the pressure as well as the oxygen concentration.

Conclusion

It is concluded that: (1) HT-1 fabric offers a definite though small advantage over the cotton fabrics; (2) there is no optimal combination of oxygen-nitrogen for the elimination of fire hazard at the pressure used, 4.6 psia.

7. Chianta, M. A., and Stoll, A. M., "Effect of Oxygen Enriched Atmospheres on the Burning Rate of Fabrics," Aerospace Medicine 35:870 (1964).

This report deals with extensions of the above work.

Summary and Conclusions

This study, designed to ascertain the feasibility of oxygen enrichment of capsular environments without increasing clothing fire hazard, has: (1) revealed that under the conditions of these experiments, with the best fire resistant clothing material

available, only a 10% increase in oxygen concentration may be realized in an oxygen-nitrogen atmosphere irrespective of pressure; similarly, a 20% increase, if argon is used; (2) demonstrated the existence and progression of the damping effect of inert gases; and (3) suggested a means of extending observations made in one gaseous environment to any other of known physical properties.

It is concluded that significant oxygen enrichment may be achieved safely only by introduction of a physiologically safe gas or gas mixtures at least twice as dense as nitrogen.

8. Dille, J. R., Crane, C. R., and Pendergrass, G. E., "The Flammability of Lip, Face, and Hair Preparations in the Presence of 100% Oxygen", Civil Aeromedical Research Institute, Federal Aviation Agency Report 63-27, Nov. 1963.

This work deals with various methods of testing to determine the hazards of the subject materials in 100% oxygen atmospheres under various ignition conditions and pressures.

Conclusions

A large margin of safety exists in using hydrocarbon face, lip, and hair preparations in the presence of 100% oxygen at or below one atmosphere. Their presence upon the hands, which may come into contact with high pressure oxygen sources probably constitutes the chief hazard.

There is some evidence that contamination with oily preparations will slightly increase the chances of ignition of solid material. Once ignition occurs, most materials burn furiously in high concentrations and partial pressure of oxygen.

Once the alcohol evaporates from pre- and post-shave compounds (in about one minute), the chances of ignition of these compounds by a static spark is negligible.

Because of the marked increase in the effects of a static spark upon these compounds at two atmospheres oxygen pressure (1520 mm Hg), their use is not deemed safe under these conditions, despite all precautions taken to prevent static sparking.

The temperatures required to ignite these compounds may occur around high pressure systems and from cigarettes, matches, microphone short circuits, or static spark.

9. Coleman, E. H., "Effects of Compressed and Oxygen-Enriched Air on the Flammability of Fabrics," Brit. Welding J. 6:406-410 (Sept. 1959)

This is an interesting picture of the very ordinary problem encountered when industrial processes utilize high pressure air and oxygen-enriched air and ignition of combustibles is imminent. Tests were made to determine the relative hazards of such exposures and to formalize the extent of protection afforded by fabric fire retardants.

Conclusions

The experiments have shown the extent to which the rate of burning of fabrics is increased in air enriched with oxygen and in compressed air.

The results of tests in oxygen-enriched air showed that a white cotton drill treated with a flame-retardant would behave similarly to a heavy Melton cloth.

Several flame-retardants were examined, and of them the best was a boric-acid/borax mixture.

There are limits of oxygen concentration or air pressure above which fabrics burn however much retardant has been added, and there are also limits of retardant above which further additions do not materially improve the protection. The limits would be different with different fabrics and retardants.

In compressed air, strips impregnated with the boric-acid/borax mixture were divisible into groups according to whether or not the strips burnt and whether combustion was by flaming or smouldering. The group which only smouldered is considered to constitute a low hazard, intermediate between the safe, non-flammable group and the hazardous group which burnt with flaming, but it is desirable for protection in compressed air that the retardant should suppress smouldering or after-glow.

Increasing the oxygen concentration by enrichment produced a greater effect than by compressing the air.

10. Roth, E. M., "Space-Cabin Atmospheres, Part II-Fire and Blast Hazards," NASA SP-48, Washington, D. C., USGPO, 1964.

This is a very comprehensive review of the entire problem and cannot be summarized here. It should be consulted per se. Although this volume is heavily oriented to its subject; much background material is given and 256 references are included for detailed study of various problem phases. (The report is now out of print).

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